THE EFFECT OF DISSOLVING A SURFACTANT IN WATER SPRAYED ON A HOT SURFACE

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Water sprays are widely used for fire suppression, both to extinguish flames on burning objects and to prevent flame spread by cooling surfaces that have still not ignited. Recently there has been renewed interest in water as an environmentally benign alternative to halons for fire extinguishment on board aircraft and vehicles, where the weight of liquid that can be carried on board is limited and it is important to minimize water requirements. One method that has proved effective in improving the fire suppression capabilities of water has been to add "wetting agents", which are typically surfactant solutions that reduce surface tension and promote foaming (Bryan 1993). Large scale tests have shown that addition of a wetting agent reduces by up to 60% the volume of water required to extinguish fires on wood, cotton bales and rubber tires. Though wetting agents have been used for about 40 years, little information is available on the mechanism by which surfactants enhance heat transfer from a hot surface to impinging droplets in water sprays. We therefore studied experimentally the effect of adding a surfactant (sodium dodecyl sulfate) to a water spray impinging on a heated surface. The experiments, so far, have been done using a non-burning metal surface. The intent has been to gain insight into the effect of surfactant addition on surface-liquid heat transfer.

Figure 1 is a schematic diagram of the apparatus used for spray cooling experiments. The spray nozzle and test surface were enclosed in an aluminum chamber (152 mm long x 152 mm wide x 254 mm high) which was mounted on a rotation stage so that the orientation of the test surface with respect to gravity could be varied. Water was supplied by a turbine pump to the spray nozzle via stainless steel tubing. The cooled surface was the flat face of a 25.4 mm diameter copper cylinder, electroplated with a 10 μm thick layer of nickel to prevent oxidation. It was placed at a distance of 50 mm from the nozzle tip, centered along the axis of the spray. Four 0.5 mm diameter Chromel-Alumel (type K) thermocouples were inserted into holes drilled 6.4 mm apart along the axis of the cylinder, with the top hole positioned 0.4 mm below the spray cooled surface. The lower end of the cylinder was bolted to a copper heater block that housed two 500 W cartridge heaters.

Two full-cone commercial nozzles (Unijet TG 0.6 and 0.7, Spray Systems Co., Wheaton, Illinois) were employed to achieve several combinations of three spray parameters: liquid mass flux, mean droplet diameter, and impact velocity, which have been identified as the main variables influencing spray cooling heat. Spray cooling experiments were done using both pure water and solutions containing 100 PPM by weight of surfactant (sodium dodecyl sulfate (SDS)). Adding 100 PPM of SDS reduces the surface tension of water by only 4% (Qiao & Chandra 1995), and has negligible influence on other physical properties such as density and viscosity. Therefore, adding a surfactant was expected to have no appreciable effect on the diameter, velocity, or mass flux distribution of droplets in the spray.

A transient spray cooling experiment was started by switching on power to the heaters until the surface temperature, as measured by the uppermost thermocouple, reached 240°C. The heaters were then switched off and the water pump activated. Water impinging on the test surface quenched it to a temperature below 100°C in a period of 10 s – 100 s, depending on the spray parameters used. Signals from the thermocouples inserted into the surface were amplified and recorded using a data acquisition system during spray cooling. Spray impingement on the hot surface was also recorded using both a 35 mm camera and a video camera.

Fig. 2 shows the surface temperature (T_W) variation during spray cooling of a surface using pure water with a mass flux $m_1 = 0.5$ kg/m^{2}s. Time t=0 marks the instant that the spray was turned on. The surface heat flux (q), calculated from the interior temperature measurements using a finite difference model of heat transfer in the copper cylinder, is also shown. At an initial surface temperature of 240°C spray droplets were in a state of film boiling, bouncing off the surface after impact, and the heat flux was low (q =0.8 MW/m^2). Heat transfer to the spray was in the transition boiling regime for 140°C < T_W < 200°C, and surface heat flux increased rapidly until it reached its maximum value, called the critical heat flux (CHF), at T_W = 140°C. Heat transfer at lower surface temperatures was by nucleate boiling, and q decreased with further reductions in surface temperature.

The effect of adding a surfactant on spray cooling heat transfer is shown in Fig. 3, where the measured variation of surface heat flux with surface temperature is plotted for both pure water and surfactant solution, at two different mass fluxes (m_1 = 2.8 kg/m^{2}s and 0.5 kg/m^{2}s). The most notable effect of adding a surfactant is to significantly increase both nucleate boiling and CHF during spray cooling: for surface temperatures between 100°C and 120°C the surface heat transfer rate was increased by 50% to 300%. The increase in nucleate boiling heat transfer was observed at all mass fluxes and impact velocities in our experiments. Photographs taken of the surface show that the surfactant greatly enhanced formation of foam during nucleate boiling on the surface. This agrees with observations made during experiments with single droplets evaporating on a hot surface (Qiao & Chandra 1995) that nucleation promotion and foaming by a surfactant are the most important mechanisms responsible for enhancing nucleate boiling heat transfer.

References

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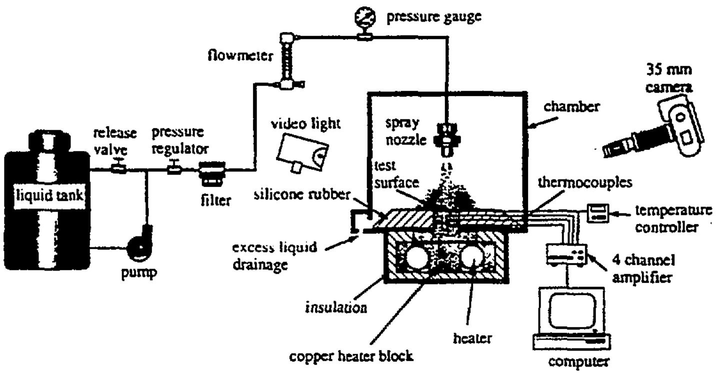

Figure 1 Schematic diagram of the spray cooling apparatus

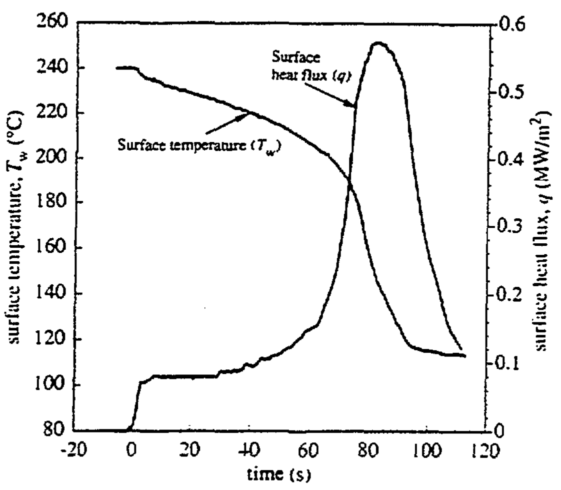

Figure 2 Calculated surface heat flux and temperature during spray cooling with pure water (mass flux = 0.5 kg/m^{2}s).

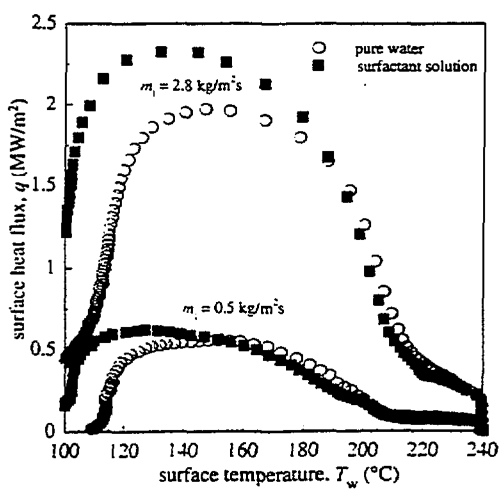

Figure 3 Effect of a surfactant on spray cooling heat transfer at two different mass fluxes.